Some Open Issues in Multi-Domain/Multi-Operator/Multi-Granular ASON/GMPLS Networks

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ABSTRACT
Large optical backbone networks may be composed of several domains, each one controlled by different administrators/operators. Besides, the bandwidth granularity of these domains may be different. Label Switched Paths (LSPs) provisioning in multi-domain/multi-operators/multi-layer network scenarios is a challenging problem actually, which has to be properly faced. In this paper, some open issues related to end-to-end bandwidth provisioning are discussed. Among others, the grooming problem in multi-layer/multi-domain optical networks and the performance degradation of recovery mechanisms due to limited inter-domain knowledge are analyzed.
Keywords: GMPLS, control plane, multi-domain, multi-layer.

1. INTRODUCTION

In the current telecommunication networks panorama, the connectivity between distant locations must traverse several heterogeneous network infrastructures deployed by different organization (e.g., different Network Operators). Indeed, the future optical networks will be based on multiple domains, technologies and control solutions making inter-domain interworking difficult, posing several new requirements. In fact, current optical networks are mainly designed to operate as a single domain controlled by a single network provider. Therefore, in a multi-domain network scenario, Network Operators are unable to efficiently cope with the increasing requirements for QoS-guaranteed end-to-end network services across dynamic access, metro and backbone optical segments. To compute, end-to-end paths with stringent quality of service requirements, it is essential to develop intelligent inter-operable control solutions which are aware also on optical layer characteristics/parameters.

In view of this, the ITU-T, IETF and OIF standardization bodies have provided architectural and protocol specifications, facilitating the interoperability amongst different network domains, technologies and vendor equipments. In this regard, a domain is any collection of network elements within a common sphere of address management or path computation responsibility [1]. Examples of domains include Interior gateway Protocol (IGP) areas, Autonomous Systems (ASes), and multiple ASes within a Service Provider network.

From the ITU-T side, the ASON architecture [2] introduces the intelligence to the optical transport network by means of a control plane. Nevertheless, the specifications in [2] follow a technology-independent definition of this control plane operation and its interfaces to the transport and management planes. The GMPLS protocol set [3], recently standardized by the IETF, has arisen as the most accepted solution for implementing the control plane functionalities in ASON. This leads to the term ASON/GMPLS, referring to a GMPLS-controlled ASON. In turn, the OIF standardization work is devoted to the User-to-Network Interface (UNI, [4]) and the interface between different ASONs (E-NNI, [5], and [6]). For each domain, the OIF E-NNI routing specifications in [6] define for each domain a higher-level (hierarchical) OSPF instance that advertises selected resource information to each other domain, allowing head domains to compute inter-domain routes. However, this approach raises confidentiality issues and sub-optimal routing due to frequent crankbacks.

Such a multi-domain network environment may connect several domains having different granularities (e.g., SONET/SDH connections and/or lambda data links). This introduces additional considerations which must be addressed, not only in the path computation algorithms, but also in selecting which domain parameters (e.g., switching capability) should be disseminated among the domains [7]. The provisioned optical channels over the DWDM-enabled ASON transport plane easily implement a 10 Gbps and beyond end-to-end communication. Thus, wavelength capacity wastage may arise, due to the mismatch between the different domains granularity, and the gap between the optical channel capacities against the client requested bandwidth (usually much lower than 10 Gbps). This poor bandwidth utilization increases the Capital Expenditure (CAPEX) in the network, as more wavelength channels are needed to support a certain amount of offered traffic. For the sake of efficiency, a number of independent client connections (LSPs) may be multiplexed into a server LSP. This operation, referred as *traffic grooming* [8], [9], allows meeting network design goals such as hardware cost minimization. In multi-domain/multi-granular network scenarios, however, end-to-end grooming poses additional requirements that will be discussed in the following sections.

On the other hand, another critical issue in nowadays optical transport networks is to assure a high resilience level. Specifically, in multi-domain/multi-granular network scenarios, intra-domain information is not shared among administration entities. This may prohibit the successful recovery of failed inter-domain LSPs, as the LSP source domain has no way to find out a feasible backup route to the destination. Therefore, some information should be shared in the event of failure to exclude both the failed link and those links without enough resources to support the backup path.

Despite big efforts have been done to standardize multi-domain/multi-operator/multi-layer aspects, there are still open issues that remain uncovered. This paper dissects some of these potential issues throughout the following sections.

2. PATH COMPUTATION IN MULTI-DOMAIN/MULTI-GRANULAR NETWORK SCENARIOS

In a typical multi-domain/multi-operator (and thus multi-vendor) optical network scenario, in each domain, vendors provide, along their equipments and respective managers, planning and bandwidth provisioning tools to be used inside the domain. Network Operators are forced to manage the different tools in the bandwidth provisioning phase, which results in Operational Expenditure (OPEX) increases. Moreover, potential errors have to be managed manually. Consequently, in such network context, there is no interoperability between vendors being necessary to perform isolated management actions inside each domain. A promising solution relies on using distributed optical control plane, which is aware of both domain and technology specific parameters to compute end-to-end paths crossing several domains. Standardized interworking across various multi-granularity network interfaces and interoperability among vendor's equipment/domains are crucial to dynamically provision end-to-end services and establish a cost effective network evolution path.

Current path computation algorithms for both provisioning and re-optimization are typically designed for small/medium scale networks and for single domain scenario, where the full availability of Traffic Engineering (TE) information is provided by the routing protocol advertisements. Current control plane solutions do not provide the adequate functionalities and TE capabilities to guarantee the requested Quality of Services (QoS) to the users while maximizing the overall network resource utilization. Even in single-domain optical networks, Network Operators have rarely implemented TE solutions because of their complexity.

To efficiently perform end-to-end path computation across multiple domains, some issue have to be considered such as the specific domain information dissemination, performance monitoring across multiple domains, fault-localization and notification, service level agreement guarantee.

Some experimental evaluations have been recently presented; however, they mainly restrict to the signalling functionality, leaving the inter-domain routing of the connections to be rather static [10], [11] and [12]. In view of this, a significant work devoted to analyze and propose solutions to enable the resource state dissemination and end-to-end path computation amongst the different administrative domains is still needed.

In large multi-domain network scenarios, characterized by hundreds of nodes, disseminating the state of all links in the local domain to all the remainder domains in the network, such as in single domain networks, leads to severe scalability limitations. To provide scalable dissemination and routing algorithms, the use of topology abstraction techniques, allowing a domain to advertise only a simplified view of its real topology, has been proposed for the single-granular network case (e.g., IP or DWDM [13]).

Further attention needs the applied inter-domain update policy to reduce the routing overhead in the network. In this regard, several inter-domain state dissemination policies have been proposed and evaluated in [14], showing that threshold-based strategies such as absolute change, relative change, and hysteresis-based yield the lowest routing overhead and better information accuracy.

Focusing now on the end-to-end inter-domain routing, two broad strategies exist for selecting the end-to-end path [12]. The first group, called per-domain strategies, works only with the local information of the domains. Hence, as the domain egress nodes to the destination are sometimes randomly selected, they yield to low bandwidth efficiency and even to unfeasible routes. This issue forces the implementation of crankback signalling functionalities in the network to reattempt the connection setup. The second group entails the deployment per domain of Path Computation Element (PCE) entities, under standardization by the IETF [1], which may work with a partial visibility of the other domains. There, the end-to-end route computation can be carried out with or without inter-PCE signalling. In the former situation, the PCE of the source domain calculates a loose route taking the aggregated network topology known. In this way, each domain is responsible for establishing the best intra-domain route between the selected border nodes. In the latter case, better resource utilization is targeted by allowing a PCE to PCE communication to ask the most appropriate routes to reach the destination. To this end, a specialized Backward Recursive PCE-based Computation (BRPC) has been proposed in [15]. Finally, once the end-to-end route is selected, an inter-domain RSVP-TE signalling would be trigged which, as said above, would be followed by the subsequent intra domain signalling/grooming actions at the different domains.

As different granularities may be involved in a multi-domain scenario, traffic grooming actions would be desirable for improved bandwidth utilization. Mention, however, that almost no studies have faced this topic. Heretofore, the majority of efforts have targeted at intra-domain grooming, having a full resource state knowledge. Typically, this is unfeasible in multi-domain scenarios, though, due to the lack of trustiness amongst the different domains. In fact, there shall be a compromise between intra-domain abstraction and performance optimization, carefully selecting which information should be propagated to the neighbouring domains. Moreover, efficient grooming algorithms dealing with physical data links, virtual links (e.g., SONET/SDH connections identified as FA-LSPs in GMPLS) and abstract links jointly should be proposed and evaluated [16]. Working with partial domain information, these algorithms should provide better performance than a per-domain approach, where only intra-domain grooming actions are possible. Even though transparent optical networks promise reduced costs resulting from the optical bypass of intermediate nodes, one should also concern about the feasibility and effectiveness of establishing end-to-end transparent LSPs crossing several domains. As end-to-end LSPs will presumably be very long, they may suffer from physical impairment effects, which would mandate electronic regeneration stages in between. Furthermore, assuming that any kind of grooming is permitted in the network, those ultra-long LSPs would be likely reused only by client LSP requests between the same source-destination node pair.

Both issues highlight the appropriateness of limiting the transparency up to a certain number of hops, which would firstly avoid the placement of specific regeneration stages and, secondly, would enhance the bandwidth efficiency in the network. Such an operation could be achieved by decoupling the lower order LSP creation from the end-to-end signalling functionality, so that that lower-order LSP placement can be decided based on any particular criteria.

3. RECOVERY IN MULTI-DOMAIN/MULTI-LAYER NETWORK SCENARIOS

Recovery in multi-domain/multi-layer networks scenarios is a complex problem which has to be properly investigated. Recent research proposals on end-to-end recovery have been proposed (see for example [17]) but without giving evidence on the impact of information dissemination needed which limit the scalability and efficiency of these approaches.

Both protection and restoration in multi-domain networks introduce additional complexities to LSPs establishment. In fact, working and protecting LSPs are generally required to be path diverse. It means that the path computation process has to provide both LSPs with path diversity, which is challenging in a multi-domain context. Besides the signalling and routing mechanisms/extensions to allow LSPs setup and maintenance across multiple domains, IETF is also defining signalling mechanisms for path protection, diverse routing and fast path restoration to ensure multi-domain path protection and restoration functions [18]. Regarding inter-domain protection, both *sequential* and *simultaneous* path computation is proposed. In the former approach, the path of the working LSP is computed without considering the protecting LSP, while in the second approach, the paths of the working LSP and the protecting LSP are computed simultaneously. However, to provide LSPs crossing different domains with recovery functionalities, some specific information must be send across different domains if that LSP need to be protected/rerouted.

For illustrative purposes, Figure 1 shows two connected ASON/GMPLS domains where an inter-domain LSP between *OXC-A* in the NO1 domain and *OXC-3* in the NO2 domain has been set up. If the link *OXC-2-OXC-3* fails, a failure notification is sent to upstream and downstream OCC nodes in the LSP route, giving them the opportunity to reroute that LSP, that is *OCC-1* receives that notification. If no alternative route is found to restore the LSP, *OCC-1* must forward the failure notification upstream to the neighbour domain. In such a case, some information belonging to the domain 2 is required to be disseminated to the domain 1 in order to exclude the failed resources in the computation of the alternate route for the LSP. For example, referring to Figure 1, the notification must include the failed link *OXC-2-OXC-3*, and *OXC-1* local data-links with the wavelength currently used by the LSP (in case of wavelength continuity constraint).

By including that information, the *OCC-B* can compute a new route for the LSP excluding those resources. To that purpose, *OCC-B* has to add those excluded resources in a XRO object in the *RSVP Path message* [19]. Upon the reception of the *Path* message at *OCC-5*, the new route segment in the domain 2 is computed excluding those resources in the incoming XRO, giving a result the new route depicted in Figure 1.

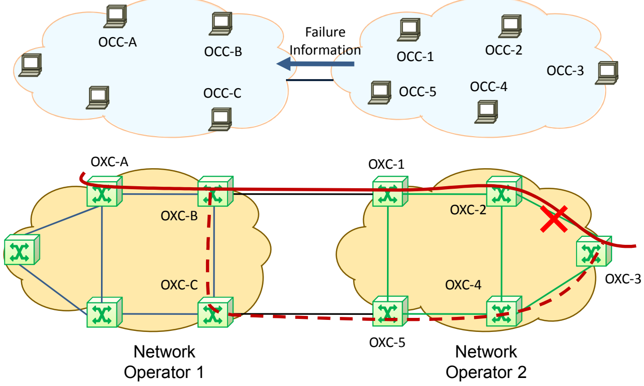

Figure 1. Example of multi-domain recovery action.

Focusing on multi-domain/multi-layer networks (e.g., MPLS over GMPLS), both network technologies, provide intra-domain recovery mechanisms able to recover LSPs from failures. For example, in MPLS fast reroute mechanisms can be used to recover MPLS LSPs from failures in that network; whereas a wider variety of mechanisms have been proposed to be used in ASON GMPLS networks. However, when the failure occurs in the border node, it is not clear how the different layers have to become coordinated and which domain has to provide the recovery mechanism. This case can be extended to a more general case in which when the optical layer cannot provide the needed recovery after the detection of an intra-domain failure, communicates this event to the client layer to provide recover in the client layer. Therefore, extensions for the intra-domain protection mechanisms to the multi-layer and multi-domain scenario must be studied.

4. CONCLUSIONS

Current network infrastructure is characterized by strong segmentation between different networks and different layers. However, multi-domain issues related to control plane and TE mechanisms applicability have not been addressed at the required level of detail. Therefore, the proper control plane extensions to provide multi-granular, multi-domain and multi-technology interoperability in IP/WDM networks have to be properly investigated. In such a way, end-to-end guaranteed services across multiple service providers in various administrative domains can be efficiently provided, allowing increasing revenues as well as reducing networks OPEX and CAPEX.

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